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QUASI-ISOSTATIC MOLDING OF REFRACTORY SAGGERS

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The advantages of quasi-isostatic molding in production of refractory saggers are considered. The proposed method, in which an elastic solid material acts as the molding medium, is a simplified version of isostatic molding.

The isostatic molding method has recently evolved into the quasi-isostatic molding method, in which an elastic solid material serves as the molding medium [1 – 3].

The quasi-isostatic molding method is a method for triaxial volume molding ensuring a uniform density in the entire volume of a molded article. Such molding does not require an expensive isostat and is carried out on standard hydraulic presses produced by the domestic industry, in quasi-isostatic molds, which in their design, installation, and operation techniques are similar to the standard molds for static molding.

The parameters of refractory saggers currently produced by static molding do not satisfy the imposed requirements. The main reason for this is the uniaxial molding, which leads to large pressure losses caused by external friction of the molding powder against the mold walls and interparticle internal friction, especially in articles of significant height. As the result of the specific molding pressure decreasing along the height of the molded article, the density and strength of this article decrease, as the distance from the molding punch grows.

One of the most efficient methods for producing molded articles with a homogeneous structure is quasi-isostatic molding.

A mold designed for quasi-isostatic molding of saggers (Fig. 1) includes the upper punch *1*, a pusher *2*, a floating matrix *3* providing for biaxial molding along the axis of application of the molding force, and an elastic molding element *4* made of polyurethane. The latter shapes the internal surface of the sagger and ensures a radial compression in a direction perpendicular to the molding pressure axis. The volume compression of material *5* is carried out as follows: the upper punch of the mold transmitting the force of the press enters the matrix and squeezes simultaneously the molding powder and the elastic molding element, as a consequence of which the material poured into the mold is subjected to a bilateral vertical compression and a radial compression via the elastic element.

The molds for quasi-isostatic molding that create the conditions for volume compression represent a combination of standard molding in static molds and isostatic radial molding; moreover, the quasi-isostatic molding conditions are developed in a single stroke of the punch. Consequently, these molds are highly efficient, which made it possible to recommend them for wide industrial application.

Due to the volume compression in quasi-isostatic molding, the height of the mold is significantly smaller than that of the molds used in uniaxial static molding to make similar saggers; accordingly, the consumption of metal is reduced.

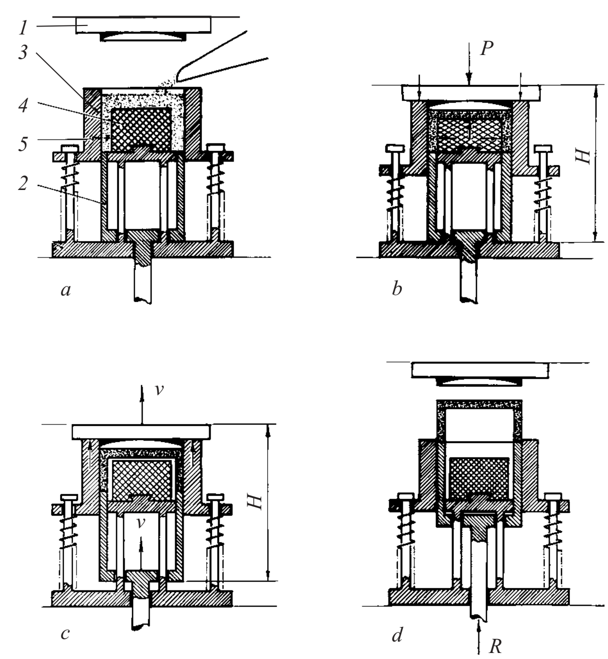

Fig. 1. The scheme of design and operation of a mold for quasi-isostatic molding of saggers: *a*) charging of molding powder; *b*) molding; *c*) removal of pressure; *d*) pushing out the finished article.

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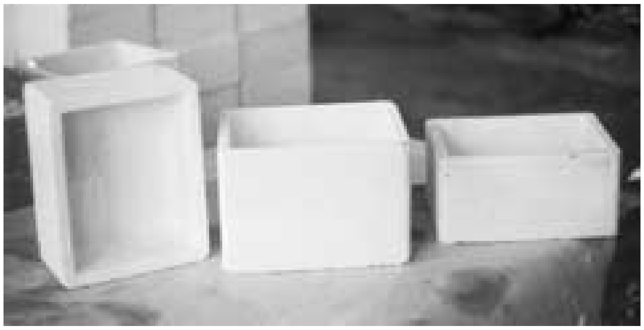

Fig. 2. Rectangular saggers made of alundum material.

An important advantage of quasi-isostatic molds is their reduced wear. It is known from the literature data [4] that the wear of molds in bilateral molding is 1.5 – 1.8 times less than in unilateral molding. In volume molding, the wear of the metal surfaces of the mold decreases several times. No wear of the elastic molding elements was observed in quasi-isostatic molds after one year of service.

The technology developed for quasi-isostatic molding of saggers and shells of round, rectangular, and square profiles from chamotte and carborundum mixtures has been implemented at a number of ceramic factories. The rectangular saggers are shown in Fig. 2. The optimum specific molding pressure for molding powders made of the specified mixtures with about 10% moisture is 20 – 25 MPa. This molding method does not require any additional operations in preparing the molding powder.

The refractory products were made of the same molding powders that are used in static molding. Drying and firing was carried out according to the procedures for refractories produced by static molding currently accepted at the factories. The refractories produced by quasi-isostatic molding exhibited stable dimensions, a homogeneous density, and the absence of defects at any technological stage. The high yield of acceptable saggers made by quasi-isostatic molding is due to the homogenous density of molded articles and the absence of internal stresses, which is a consequence of the volume application of pressure to the molding material.

Molds for quasi-isostatic molding are installed on standard hydraulic presses produced by the domestic industry (Fig. 3). They are simple, reliable in operation, and consume less metal than the standard molds for static molding of similar articles.

The efficiency of quasi-isostatic molds is not lower than that of static molds, and in some cases is slightly higher due to the lower specific molding pressure required. The pressure is 20 – 50% lower, which makes it possible to use less powerful presses.

The duration of a complete molding cycle (inclusive of placing the molded sagger on a drying car) is not more than 1 min. The designs developed for industrial molds allow for the automatic molding conditions. Furthermore, the design of the molds makes it possible to produce saggers of different height and shells of different standard sizes in the same mold. The transition from one standard size to another is performed without removing the mold from the machine, by means of controlling the height of charging and replacing the molding buffer.

Fig. 3. A mold for quasi-isostatic molding of a round sagger.

The use of the same mold for saggers and shells of various standard sizes allows for substantial savings in metal consumption and savings in labor not only in making molds but also in operation, since there is no need to remove a mold and install another in transition to a new product. One operator can perform a readjustment of the mold in several minuets.

The industrial application of saggers made by quasi-isostatic molding demonstrated that the turnover of saggers increased 5 – 7 times compared with saggers made by static molding.

Sagger properties

Increase in turnover of sagger, times	5 – 7
Shape of sagger	Round, rectangular, square
Refractory material	Alundum, chamotte, carbocorundum, mullite-corundum
Maximum size of sagger, mm:	
diameter	240, 315, 330
height	170, 200
Molding duration for one sagger (with manual charging of molding powder and manual placing of the sagger on a car or a drying rack), sec	53 – 60
Decrease in molding pressure to get the same apparent density (in a nonfired article), %	20 – 25
Decrease in push-out pressure	Several times

Sagger properties (*continued*)

Metal consumption on molds compared with static molds, %	< 30
Machinery used	Hydraulic press
Method for preparing molding powder	Same as in static molding
Number of molding cycles before the first repair of the mold, thousand units:	
in quasi-isostatic molding	22 – 23
in static molding	13 – 15
Molding buffer resistance, thousands of molding cycles	> 100

It is known that the service parameters of saggers become significantly better with increased chamotte content. The quasi-isostatic molding technology makes it possible to increase the chamotte content from 50 to 80 – 85%. Furthermore, this molding technology allows for producing saggers with thinner walls, for instance 12 mm instead of 17.5 mm, which makes it possible to decrease the material consumption in the production of refractory saggers.

Simultaneously with the implementation of the quasi-isostatic molding technology for saggers, we analyzed the technological processes of sagger production at the same factories. It was established that one of the reasons for poor quality of saggers is the inhomogeneity of sagger mixtures (unsatisfactory mixing of initial components and inhomogeneous distribution of the components in the mixture). A duration of mixing equal to 10 – 15 min is evidently insufficient, especially for chamotte mixtures, in which clay previously dried in a spray drier is introduced. The insufficient time of mixture preparation determines its low plasticity, which has a negative effect on the density of molded articles and on the homogeneity of the distribution of the batch components in molded articles.

As a result, certain portions of articles with a higher clay content have higher shrinkage in drying and firing than other sites with a higher chamotte content. Consequently, significant differences in crackle sites are formed, which considerably impairs the properties of saggers.

Another negative effect on the quality of saggers is low firing temperature, which in some cases does not exceed the service temperature. Some factories have an erroneous notion that refractories can be fired at a temperature below their service temperature. In such cases, saggers in service are subjected not only to additional shrinkage, but to deformation as well. Therefore, refractories have to be previously fired at a temperature exceeding their service temperature.

The mechanical strength of saggers is largely provided by the material structure determined by the firing conditions. The results of a petrographic and x-ray phase analysis of the material of chamotte saggers fired at 1310 – 1320°C demonstrated that the bulk of the material represented a nondecomposed argillaceous compound, and only certain areas contain seeds of mullite crystals. An increase in the firing temperature to 1350°C increases the degree of mullitizing. The mullite content in the material of such saggers grows to 40 – 41%. An exposure for 4 h at the final firing temperature increases the mullite content to 50% and significantly decreases the amount of cristobalite (from 13 to 4%). It is known that cristobalite in heating (180 – 270°C) and subsequent cooling undergoes modification transformations accompanied by an abrupt volume modification, which initiates cracks in saggers due to multiple heating and cooling cycles.

Free quartz has a similar effect. Therefore, the presence of a large amount of cristobalite and quartz in sagger material is extremely undesirable. The firing conditions for saggers should be selected to ensure the formation of material with a preset structure.

Multiple temperature effects on the sagger material in service does not affect its structure. Thus, the material of saggers made by quasi-isostatic molding after 22 cycles in an industrial tunnel furnace exhibited a stable amount of mullite and stable quantities of cristobalite and quartz. This suggests that secondary mullite has not been formed. Accordingly, one cannot assume that the structure of the material is improved in service. The technology of joint firing of a molded unfired sagger containing molded porcelain articles is not justified as well. A sagger ought to be fired in an unloaded state at a temperature at least 50°C above its service temperature. Exposure at the final temperature should be 4 – 6 h.

The quality of saggers directly depends on the molding method. The existing static molding technology with a unilateral uniaxial application of pressure does not provide for saggers with a homogenous density, due to the substantial height of saggers. An efficient method for avoiding heterogeneous density in the volume of a molded piece is quasi-isostatic molding with triaxial compression, which not only avoids different densities in a molded article but also prevents anisotropy of its structure. This method is the simplest variant of isostatic molding and does not require expensive isostats or additional production space.

Quasi-isostatic molding is a highly efficient process. The molds designed for this technology are successfully used in automated operation of hydraulic presses.

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